REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
07-06-2010	CONFERENCE PROCEEDING	2010-2010

4. TITLE AND SUBTITLE
Mirror Technology Development for the International X-ray Observatory Mission

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
William W. Zhang

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NASA Goddard Space Flight Center
Greenbelt, MD 20771

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA Goddard Space Flight Center

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA GSFC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at Mirror Technology Days, Boulder, Colorado, USA, 7-9 June 2010.

14. ABSTRACT

The International X-ray Observatory (IXO) mission requires a large mirror assembly with an angular resolution of 5 arcseconds half-power diameter and an effective area of 3 square meters. We are developing a glass slumping technique that is coming close to meeting these requirements. In the last few years significant and steady progress has been made in mirror segment fabrication, metrology, and alignment and integration. In this paper, we will present a status update on the various components of the technology, including mirror fabrication, glass screening and strengthening, coating, mirror mount and metrology, alignment and integration. We will also present our plan and expectations for the next couple of years.

15. SUBJECT TERMS
International X-ray Observatory, X-ray optics, Space Optics, Lightweight optics, Glass slumping, Alignment

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18.NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Hans-Peter Dumm
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	19	**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			505-853-8397

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

Mirror Technology Development for The International X-ray Observatory Mission

Will Zhang

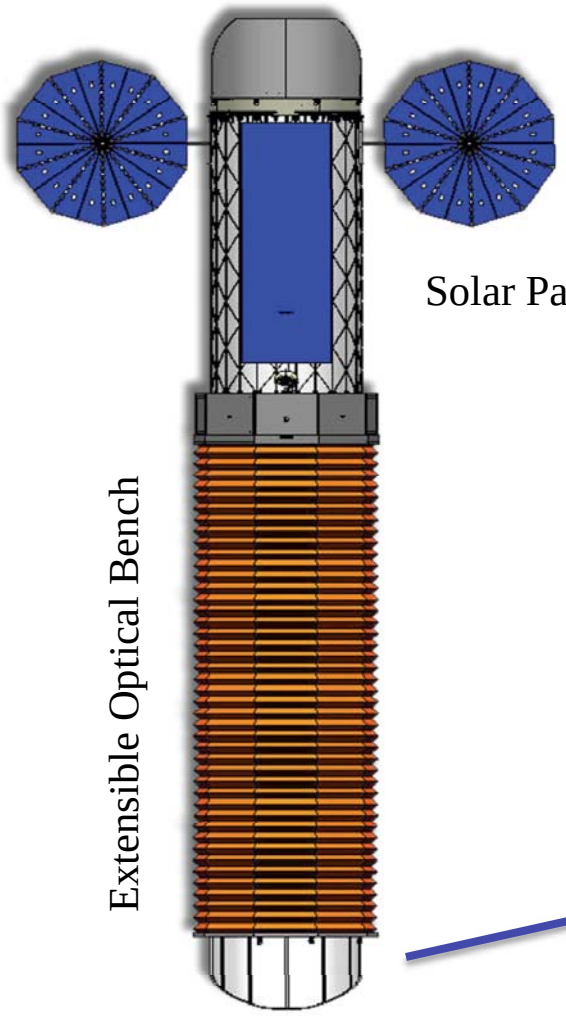
IXO Mirror Technology Lead Scientist

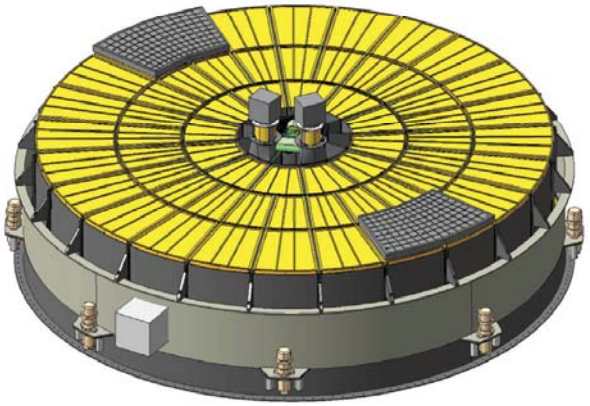
X-ray Astrophysics Laboratory

NASA Goddard Space Flight Center

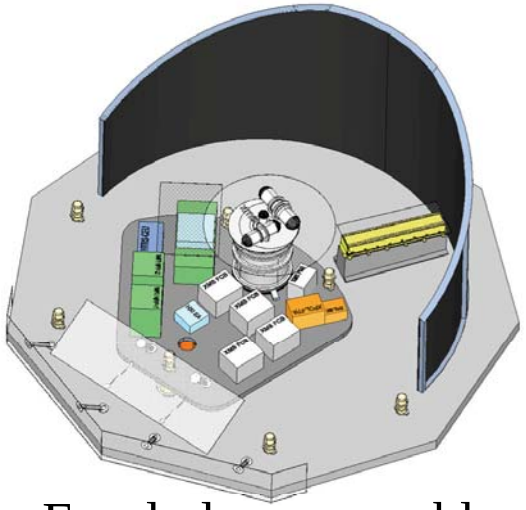
International X-ray Observatory (IXO)

ESA
JAXA
NASA





Mirror Assembly



Focal plane assembly

Lightweight and High Resolution X-ray Optics is Needed

State of the Art

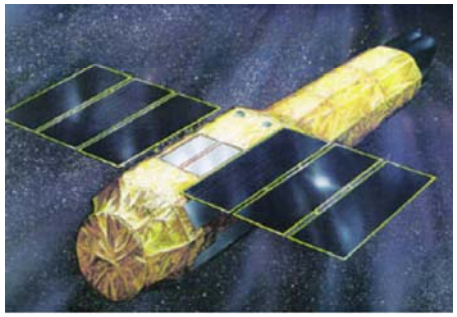
Chandra

0.1 m^2
0.5 arcsecs

XMM-Newton

0.4 m^2
15 arcsecs

Suzaku



0.2 m^2
120 arcsecs

IXO Requirement

3 m^2
5 arcsecs

Modular Design of Mirror Assembly

	1 FMA		1 FMA
			
12 Inner Modules Radius: 370-690mm	24 Middle Modules Radius: 740-1110mm	12 Outer Modules Radius: 1160 - 1610mm	60 Modules
			
143 P/H Pairs	155 P/H Pairs	103 P/H Pairs	15,816 Mirror Segments
			

IXO Mirror Technology Development Objectives

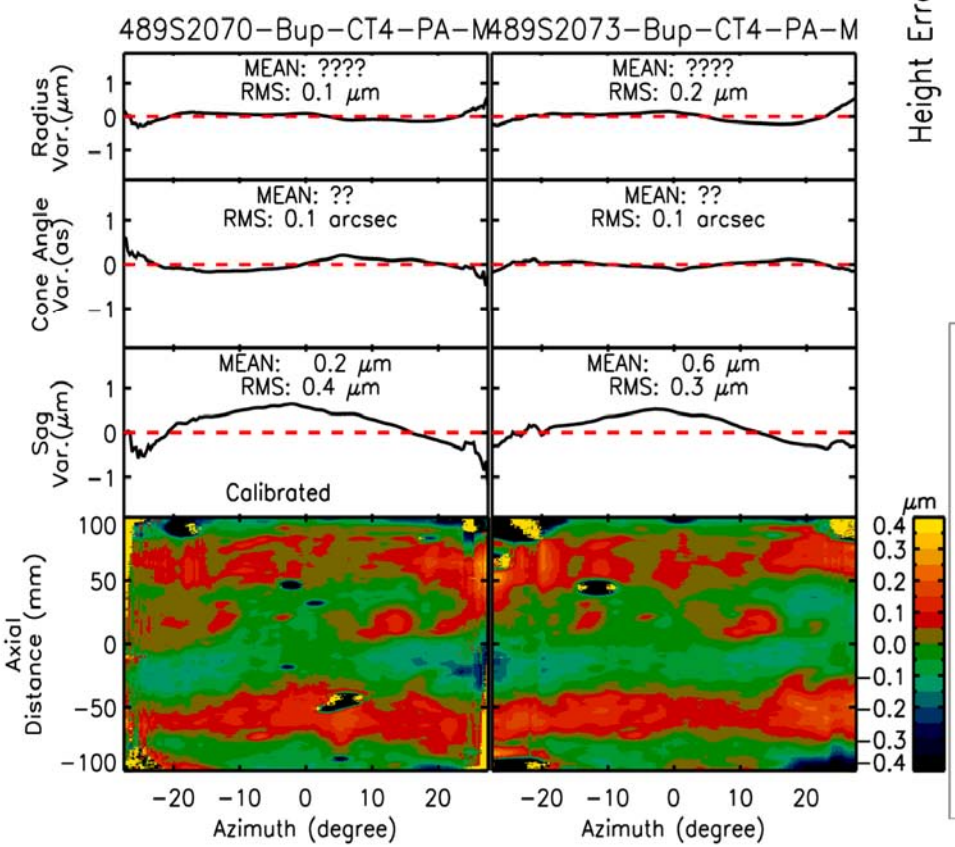
- Identify problems unique to IXO mirrors that have not been encountered by, or solved for, previous missions
- Devise solutions to these problems; Demonstrate their validity through analysis and experimentation
- Establish design principles and build prototypes to prove that they meet requirements: angular resolution, effective area, mass, schedule and budget
- Subject the prototypes to X-ray and appropriate environment tests to demonstrate TRL-4, 5, and 6

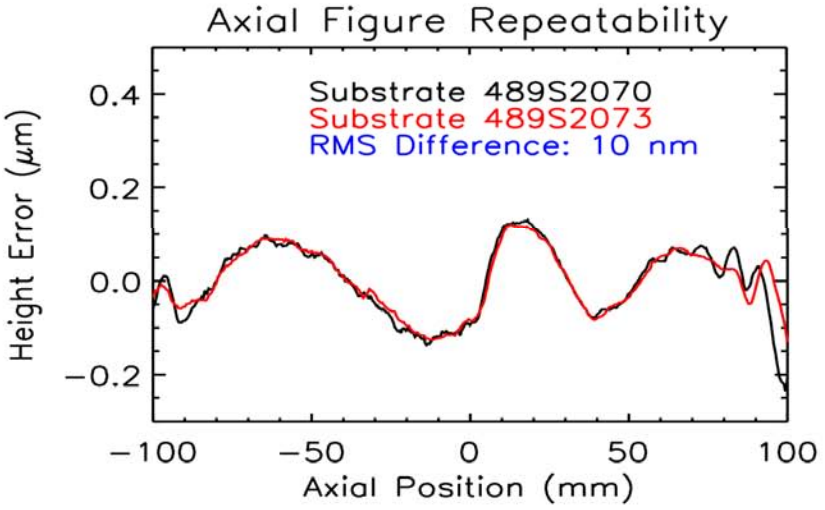
Demonstrate the feasibility; Find out what's and who's out there to engineer and build the telescope!

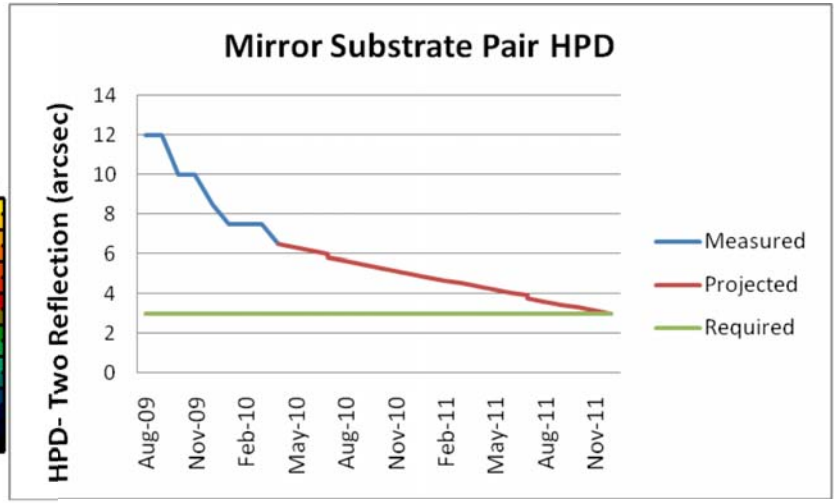
Focus of Technology Development

Major Category	Minor Category	Objectives
Mirror Segment Fabrication	**Forming Mandrel Fabrication**	(1) Make mandrels for tech dev.; (2) Develop and optimize production techniques
	Slumping	(1) Replicate forming mandrel figure
	Post-Slumping Cutting	(1) Cut replica to dimension; (2) Create smooth edges; (3) Not change figure
	Coating	(1) Maximize reflectivity without changing figure
Alignment and Integration Techniques	**Suspending**	(1) Set mirror segment to its natural figure
	Temporary Bonding	Temporarily attach mirror segment to strongback such that mirror segment is free of stress and distortion
	Alignment	Properly locate and orient mirror segment
	Permanent Bonding	Permanently attach mirror segment to module housing
Module Design, Construction, and Test	**Housing Material Selection**	Achieve best possible compromise among CTE, thermal, mechanical, machinability, availability, etc.
	Design & Analysis	Achieve best possible compromise among optical, mechanical, thermal, and other aspects
	Construction	Effectively combine and integrate the “alignment and integration techniques” to install mirror segments into housing
	Tests	X-ray tests for angular resolution and effective area; Environment tests

Slumping - Status



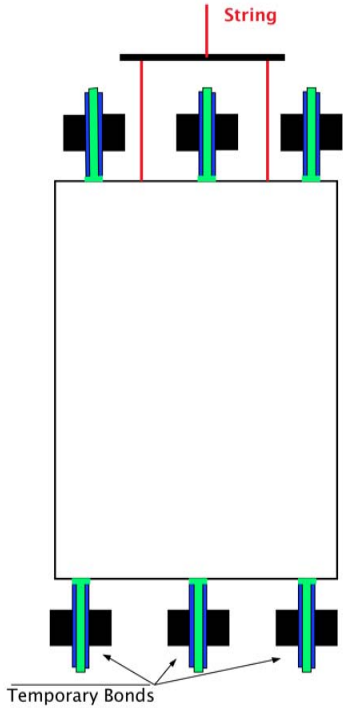




Mirror Fabrication Progress

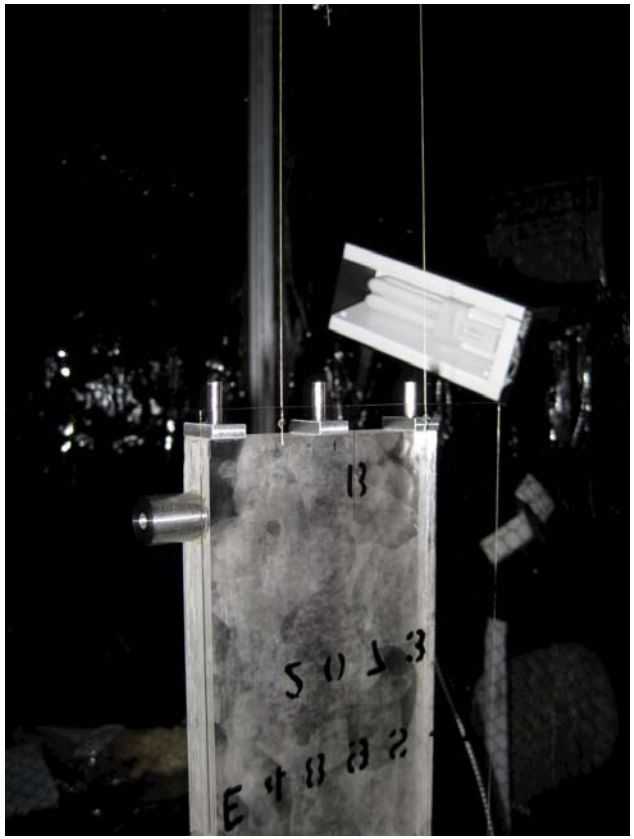
Date	HPD (two reflections	Comment
December 2008	~16”	Normal incidence metrology, Full illumination X-ray tests; 60-deg segments
August 2009	~12”	Normal incidence metrology; 60-deg segments
October 2009	~10”	Normal incidence metrology; 30-deg segments
December 2009	~8.5”	Normal incidence metrology; 30-deg segments
January, 2010	~7.5”	Normal incidence metrology; 30-deg segments
April, 2010	~6.5”	Normal incidence metrology; 30-deg segments, Using IXO mandrels
December 2011	~3”	Using mandrels meeting IXO requirements; Meeting IXO requirements

Temporary Bonding - Status

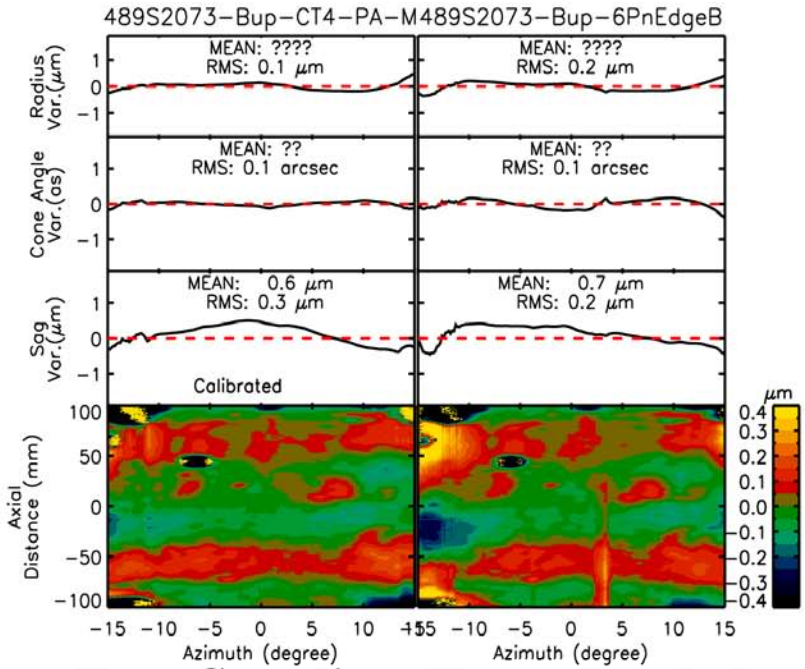


Face-On View

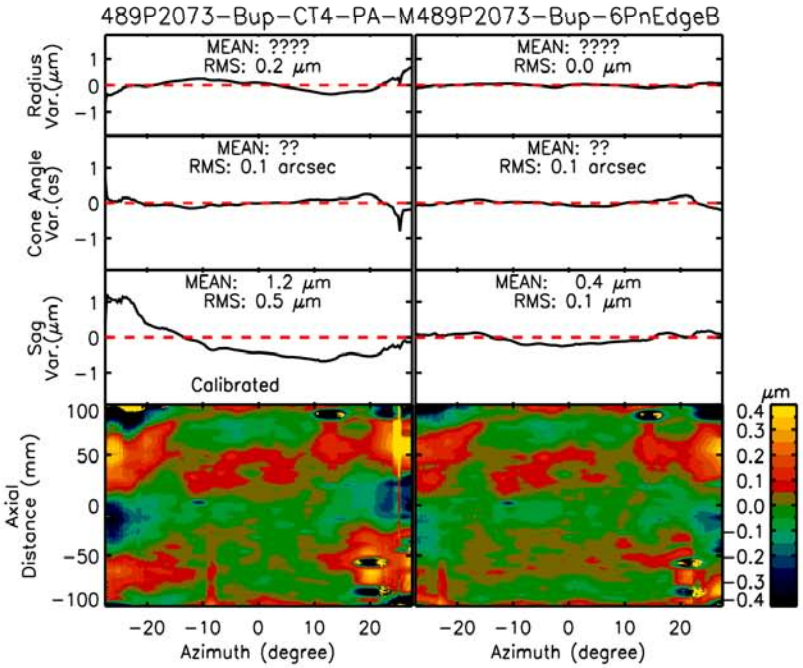
Edge-On View



Temporary Bonding - Status



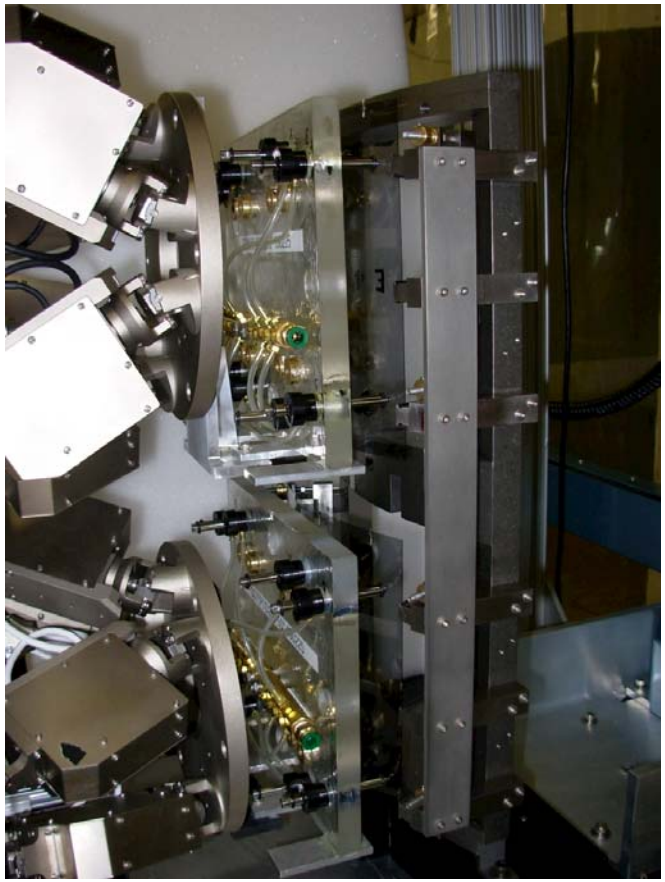
Free-Standing Temp-Bonded

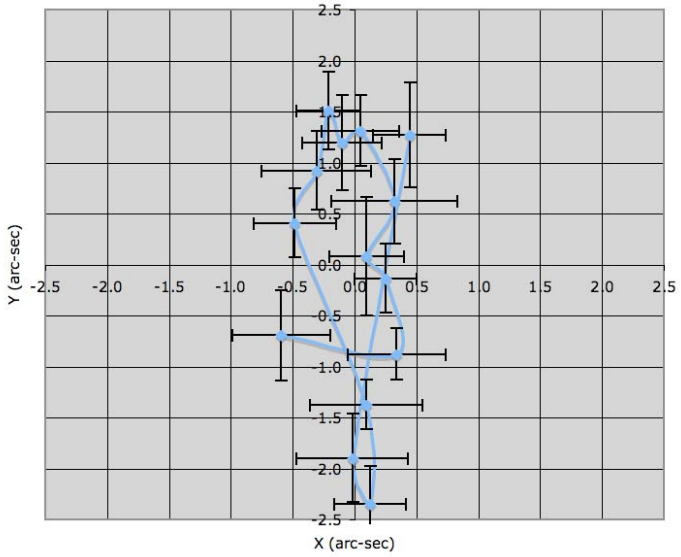


Free-Standing Temp-Bonded

- The temporary bonding process probably has met requirements, at least for smaller mirrors
- More detailed and quantitative analysis is underway
- Need to conduct experimentation with big mirror segments

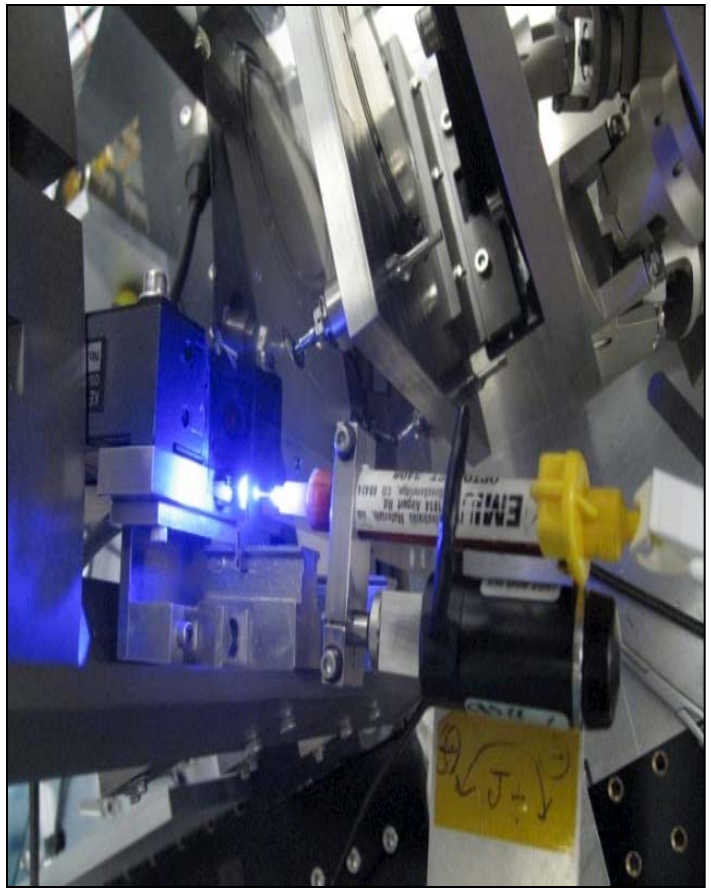
Alignment - Status

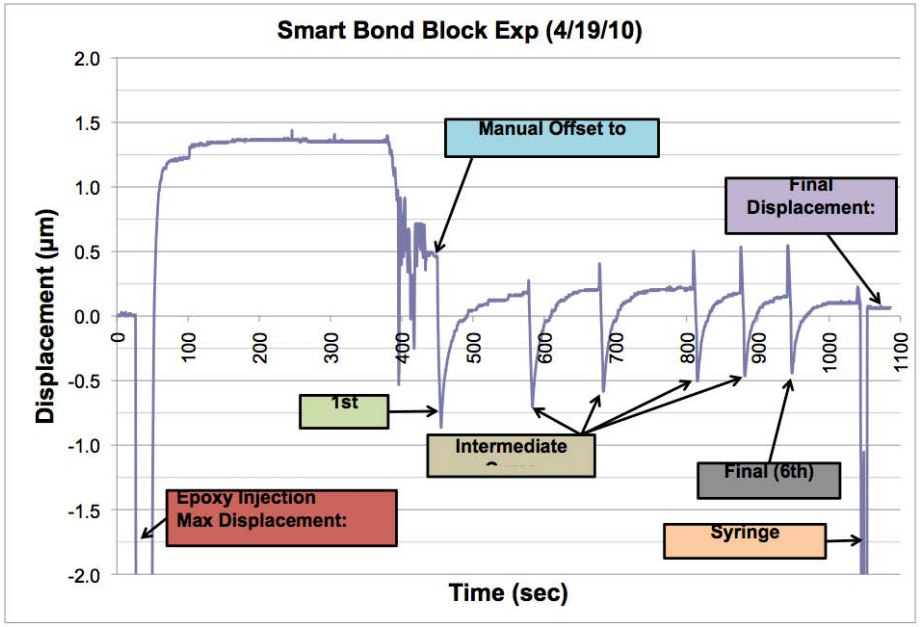




- Achieved excellent focus
- Improvement needed
  - Equipment stability
  - Lab temperature stability

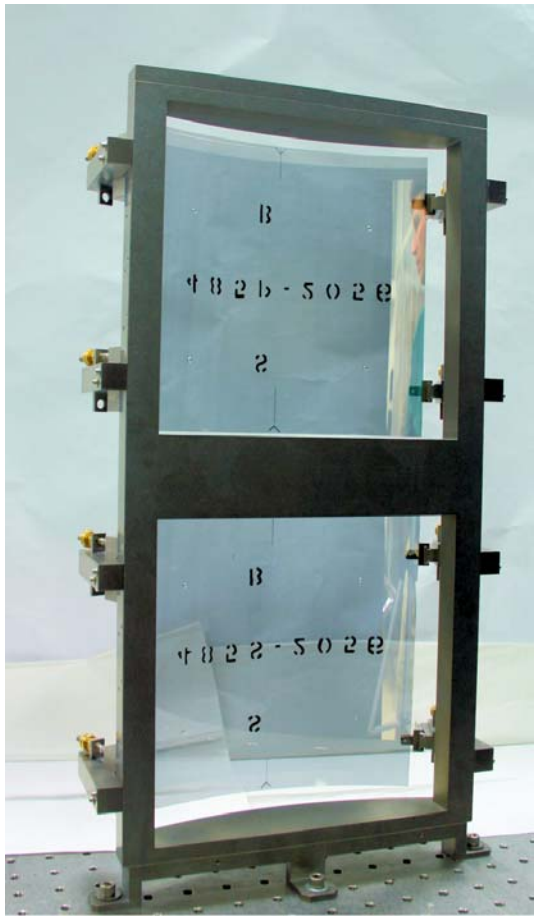
Permanent Bonding - Status





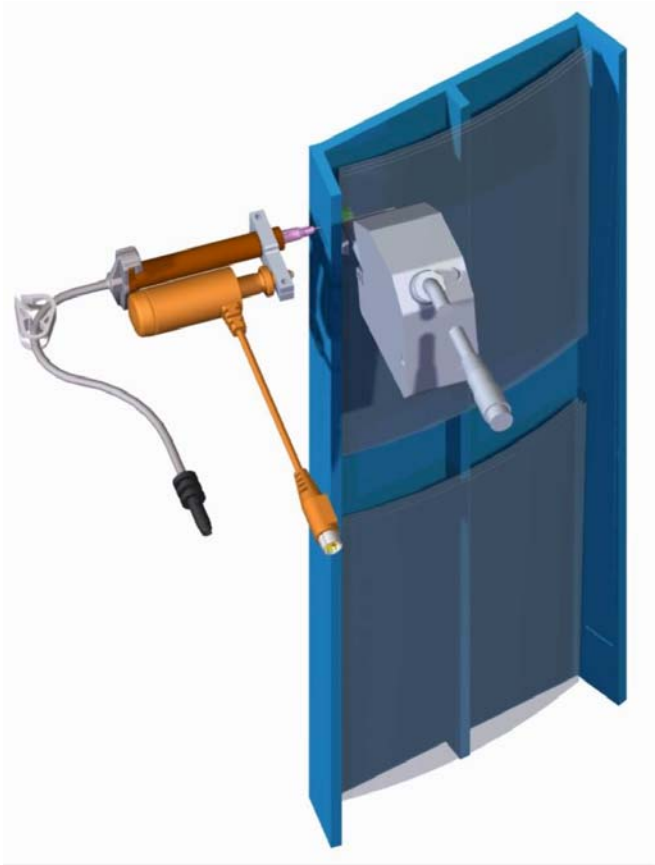
- Active compensation to counter the effects of epoxy injection hydraulic and shrinkage forces
- Achieved single point bonding accuracy of 0.1μm, meeting requirements

Mirror Housing Simulator (MHS) – TRL-4



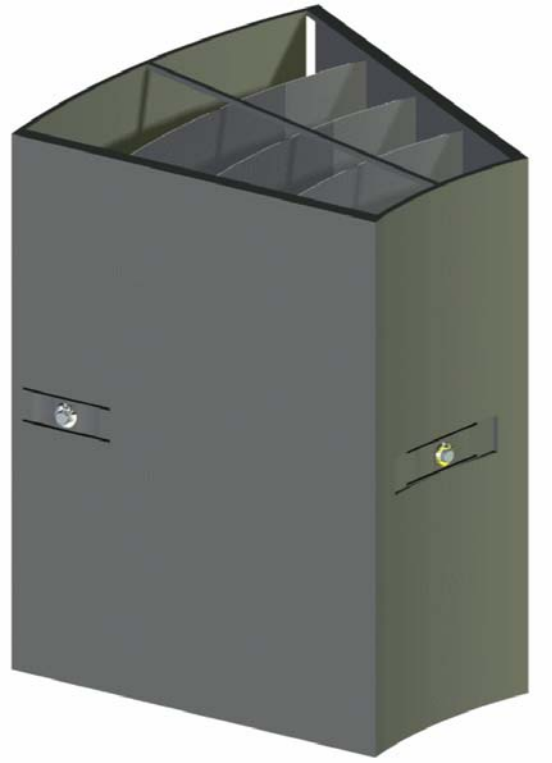
- Designed and fabricated to hold one pair of mirror segments
- Fully open and accessible to facilitate alignment, bonding, and metrology verification

Mini-Module (TRL-5)



- Capable of handling multiple shells, fully testing the entire process of installing mirror segments into a module
- Capable of undergoing a full battery of tests, performance as well as environment

Flight-Like Module (TRL-6)



- Fully flight-like in every aspect
- Populated with both real mirror segments and mass dummies
- Will undergo a full battery of tests: X-ray, vibration, acoustic, thermal-vacuum, etc.

Angular resolution: 3.8” (half-power diameter or HPD)

Mirror Technology Development Team

M. Biskach[3], P.A. Blake, G. Byron[3], K.W. Chan[1], T. Evans[3],
C. Fleetwood[2], C. He[2], M. Hill, M. Hong[3], Lalit Jalota[1],
L. Kolos, J.M. Mazzarella[3], R. McClelland[3], L. Olsen[3], R. Petre,
D. Robinson, T.T. Saha, M. Sharpe[3], W.W. Zhang
NASA Goddard Space Flight Center
[1] University of Maryland, Baltimore County
[2] Ball Aerospace and Technologies Corp.
[3] Stinger Ghaffarian Technologies, Inc.

M.V. Gubarev, W.D. Jones, T. Kester, S.L. O'Dell
NASA Marshall Space Flight Center

D. Caldwell, W. Davis, M. Freeman, W. Podgorski, P.B. Reid,
S. Romaine
Smithsonian Astrophysical Observatory

Outlook

- Mirror fabrication milestones
  - Consistent at ~5” HPD (two reflections) by December 2010
  - Consistently meeting requirements (~3” HPD two reflections) by December 2011
- Improvement of metrology to identify and isolate sources of error
  - Metrology mount
  - Upgrade null lens
  - Check for systematic effects
  - Cross-check figure quality using both normal and grazing incidence measurements
- Suspension Mount, Alignment, and Transfer (SMAAT)
  - Perfect and understand edge-bonding (December 2010)
  - Streamline and upgrade the alignment setup to improve thermal and structural stability (December 2010)
  - Transfer and bond single pairs of mirrors in mirror housing simulator (MHS) to achieve TRL-4 (July 2010)
  - Co-align and transfer and bond multiple mirror pairs to achieve TRL-5 (May 2011)
- Module
  - Housing material selection by December 2010
  - Design, analysis, and partial tests in 2011
  - Full TRL-6 by November 2012

Small Technology Firms that Have Made Direct Contributions to IXO Mirror Technology Development

4D Technology, Tucson, AZ
Optimax Systems, Inc., Ontario, NY
QED Technologies, Rochester, NY
Rodriguez Precision Optics, Gonzales, LA
Dallas Optical Systems, Inc., Rockwall, TX
RAPT Industries, Inc., Freemont, CA
Reflective X-ray Optics LLC, New York, NY

Acknowledgements

The work is supported in part by

NASA IXO Project Office

Goddard Space Flight Center Internal Research and Development Fund

A NASA *Astronomy and Physics Research and Analysis (APRA)* Grant